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(54) **METHOD OF CONDUCTING CATALYTIC CONVERTER MULTI-PHASE REACTION**

**METHODE ZUR DURCHFÜHRUNG EINER MEHRPHASENREAKTION MIT EINEM
KATALYTISCHEN KONVERTER**

**PROCEDE POUR EFFECTUER UNE REACTION MULTI-PHASE AVEC UN CONVERTISSEUR
CATALYTIQUE**

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Description

[0001] The present invention relates to a method of conducting a continuous multi-phase catalytic reaction and is particularly, though not exclusively, applicable to the catalytic conversion of syngas, produced by the reforming of methane, to hydrocarbon fuels, by a Fischer-Tropsch type of synthesis. Other reaction systems to which the method is applicable include various slurry reactions for the production of petrochemicals, the production of oxygenates from synthesis gas and dehydrogenation reactions.

[0002] Three-phase catalytic reaction systems are used in a number of chemical processes and their application in the petrochemical industry appears to be increasing. Of the three-phase systems in use, mechanically agitated, loop and bubble column slurry reactors contain small catalyst particles dispersed in the liquid. In most applications, the liquid will have to be separated from the slurry to remove liquid products or for catalyst regeneration purposes. In those cases where the liquid is an inert medium, occasionally, it may have to be replaced due to degradation or the build-up of impurities.

[0003] Mechanically agitated slurry reactors are particularly convenient for batch process due to the low mass-transfer and heat resistance. These features also make them suitable for the determination of reaction kinetics in the laboratory. A serious disadvantage and limitation of this reactor type, however, is the difficulty in the separation of catalyst particles in any continuous operation.

[0004] Commercially, it is only mechanically agitated reactors that are used in the hydrogenation of double bonds in oils from cottonseed, soybean, corn, sunflower etc. By employing a nickel catalyst, the products include margarine, shortening, soap and greases. The choice of reactor is based on the low diffusivities and high viscosities of the fatty oils. Fixed-bed operation has been proposed due to the advantage of completely catalyst-free products without filtration. A number of other hydrogenation reactions are also carried out in agitated reactors, e.g. the hydrogenation of nitrocompounds.

[0005] The operation of bubble column slurry reactors is simple, since mechanically moving parts are avoided. Combined with the low diffusional resistance and efficient heat transfer, these reactors are attractive for many industrial processes. However, solid-liquid separation is usually performed outside the reactor in elaborate filtering and settling systems. The catalyst slurry is to be recycled to the reactor, sometimes with the use of a slurry pump. Thus, serious problems may be encountered in the continuous operation of bubble column slurry reactors.

[0006] As world oil resources diminish it is becoming more attractive to use natural gas as an energy source and methods of upgrading this to higher hydro-

carbon fuels are increasing in importance.

[0007] It is therefore an object of the invention to provide a continuous method of conducting a multi-phase catalytic reaction which does not suffer the drawbacks of the prior art.

[0008] It is a particular object of the invention to provide such a process which is well suited to use in the conversion of natural gas via syngas to diesel fuel.

[0009] According to the invention, there is provided a method of conducting a continuous multi-phase catalytic reaction in which the product includes at least one liquid component and the catalyst is a finely divided solid, the method comprising: introducing reactants into a slurry of reactants, product and catalyst in a reactor vessel; separating the liquid product from the remainder of the slurry by means of the filter member; and maintaining the slurry; in state of constant agitation by introducing gaseous components into the slurry as a stream of bubbles; characterised by establishing a mean pressure differential of from 1 to 1000 mBar across the filter member and causing fluctuations or oscillations about the mean pressure differential; and in which a gas space above the slurry is in communication with the filtrate or any gas space above the filtrate, in addition to any communication by way of the slurry itself.

[0010] Such a method is relatively simple yet effective. The separation step, generally considered to be particularly problematic, is achieved without undue complication and under proper operating conditions the filter member is self-cleaning.

[0011] The reactants may be CO and H₂, for example from the reforming of methane. The reaction may then be a catalytic conversion by a Fischer-Tropsch synthesis, producing methanol and higher hydrocarbons.

[0012] Preferably, the gaseous components include any gaseous reactants. Preferably, the slurry is maintained in a turbulent state by the gas bubbles.

[0013] Preferably, a pressure differential is achieved by applying an excess pressure to the slurry side of the filter member and/or by applying a negative pressure to the product (filtrate) side of the filter member. Preferably, the pressure differential is achieved, at least in part by maintaining the slurry at a level above the level of the product on the filtrate side of the filter member, by means of a constant level device on the filtrate side of the filter member. The pressure differential should not be allowed to increase beyond a fairly low maximum limit since the filter unit would otherwise tend to clog. Communication between the space above the slurry and the space above the filtrate prevents the build-up of pressure differentials in excess of that corresponding to the hydrostatic pressure.

[0014] The pressure fluctuations or oscillations may be achieved in various ways. The pressure fluctuations or oscillations may be carried out by the turbulent motion of the slurry in the reactor and/or by gas bubbles rising on the outside of the member, which may themselves give rise to turbulent flow conditions. This may be

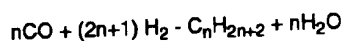
transferred or enhanced perhaps by resonance effects to the filtrate by way of communication between the gas volume above and the slurry and the gas volume above the filtrate.

[0015] The pressure fluctuation value may be of the order of the pressure differential, for example from 10 to 200% of the pressure differential. The actual value of the pressure differential is from 1 to 1000mBar, preferably 2 to 50mBar. Very good operational results may be obtained in the range of 2 to 10mBar in the case of a Fischer-Tropsch conversion of syngas to hydrocarbon products.

[0016] The filter member is preferably in the form of a filter unit which defines internally the filtrate zone and which includes a filter element separating the filtrate from the slurry. Preferably the filter element is generally cylindrical and its axis is generally vertical in use though it may be inclined by as much as 10° or even 30° to the vertical. The member material and catalyst are preferably selected so that the maximum hole or pore size in the filter element is of the same order of magnitude as the catalyst particle size, the particle size preferably being not less than half the pore size. However, it would be possible for the catalyst particle size to be larger than the maximum pore size, with the pore size being of the same magnitude or less.

[0017] The invention also extends to a method of converting natural gas (methane) to higher hydrocarbon fuels which involves initially reforming the methane to produce carbon monoxide and hydrogen, subjecting the CO and H₂ to catalytic conversion by a Fischer-Tropsch synthesis using the method mentioned above to form higher hydrocarbon fuels such as liquid paraffin waxes, and subsequently separating and/or cracking these products to produce the required range of hydrocarbons.

[0018] The mechanism of the Fischer-Tropsch synthesis is probably quite complicated but the formation of hydrocarbons can be summarised as follows:-



[0019] A preferred catalyst and process is described in EP-A-313375.

[0020] When diesel fuel is produced in this way it is vastly superior to conventional diesel in terms of its quality and properties. Firstly, it contains no sulphur or aromatics, which is important from an environmental point of view. Secondly, it has a very high cetane number and can therefore be blended with lower grades of diesel fractions in order to give a product which meets premium range standards. Thirdly, it contains virtually no harmful compounds that generate soot when burned and needs fewer additives for problem free use at low temperatures.

[0021] The invention may be carried into practice in various ways and some embodiments will now be described by way of example with reference to the

accompanying drawings, in which:

Figure 1 is a schematic section through a three-phase slurry reactor for performing a method in accordance with the invention;

Figure 2 is a simplified schematic section through a part of a reactor showing an alternative system for achieving the fluctuations in pressure;

Figures 3, 4 and 5 are views similar to Figure 2 showing three ways of adjusting the pressure differential across the filter member.

Figures 6 and 7 are views similar to Figures 3 to 5, showing two further variants.

[0022] The reactor vessel 11 in Figure 1 comprises an outer casing 12 defining the reactor vessel 11 and within the casing 12 a filter unit 13. The housing 12 has a gas inlet 14 at the bottom which, in the case of a syngas conversion process, would constitute the reactant inlet. Above the gas inlet 14, there is a gas delivery device such as a gas-permeable frit plate 15 which supports the slurry 16 in the reactor vessel 11, and at the top of the casing 12, a gas outlet 17. The gas outlet 17 is controlled by a choke or valve 18. The casing also has an inlet 19 and an outlet 21 for the slurry.

[0023] The filter unit 13 comprises a generally vertical cylindrical filter element 22 in contact with the slurry 16. The filter element is in the form of a fine meshed screen though it could alternatively comprise helically wound metal threads, sintered metal particles or narrowly separated fine vertical threads. It houses a constant level device in the form of a vertical pipe 23 which terminates below the top of the filter unit 13. The pipe 23 leads to a filtrate outlet 24 which in turn leads to a collector 25 and to an outlet valve 26. A tube 27 extends from the space 28 within the filter unit 13 above the top of the pipe 23 to the space 29 within the top of the reactor 11 above the filtrate 16. An opening 31 in the tube 27 connects the two spaces 28, 29.

[0024] In operation, gaseous reactants are introduced to the reactor vessel 11 via the inlet 14 and the plate 15. The reactants form bubbles in the slurry 16 which pass upwards past the filter unit 13. The slurry 16 consists of a liquid phase of the reaction products and a catalyst in finely divided form. The gaseous reactants react as they contact the catalyst, thus adding to the products in the slurry.

[0025] At the same time, the products pass through the filter element 22 to form a product filtrate 32 which is free of catalyst. Any gaseous products and unreacted reactants can be vented through the outlet 17 and subsequently treated and/or recycled. The product filtrate 32 leaves the filter unit 13 via the constant level device 23 and outlet 24 and is collected in the collector 25 for regulated continuous or periodic removal.

[0026] The difference in level between the slurry 16 and the product filtrate 32, determined by the constant level device, results in a pressure differential across the

filter element 22. This helps to convey the liquid product through the filter element 22.

[0027] It might be expected that, under these conditions, the catalyst would clog the filter element, however, this is found not to be the case, provided that the pressure differential is not too great. The introduction of the reactants together with the connection of the gas spaces 28, 29, and the generally turbulent conditions in the reactor vessel 11 combine to cause fluctuations in the pressure differential across the filter element 22. These in turn cause fluctuations in the liquid flow through the filter element 22 resulting in an anti-clogging effect. This may be enhanced by the movement of the gas bubbles past the surface of the filter element 22.

[0028] An alternative embodiment outside the scope of the invention is shown in Figure 2. In this case the filter unit 41 has no tube 27 connecting the space 28 to the space 29 in the reactor (not shown). Instead, a cylinder and piston assembly 42 is connected to the space 28. By reciprocating the piston, a pulsating pressure is produced resulting in the desired fluctuation in the pressure differential across the filter element 22. This arrangement can of course be used in conjunction with the embodiment shown in Figure 1. Communication between the spaces above the slurry and the filtrate may be provided by a tube (not shown) having a restriction or choke limiting the transmission of pressure pulses to the space above the slurry, which would otherwise have tended to eliminate the net effect of the reciprocating piston. The tube would nevertheless control the static pressure differential, and this variant would then be within the scope of the invention.

[0029] The constant level device 23 can be made adjustable in order to provide a degree of control over the pressure differential across the filter element 22. Three ways in which this can be achieved are shown in Figures 3, 4 and 5.

[0030] In the filter unit 51 of Figure 3, both the vertical pipe 52 and the tube 53 are slidably mounted with respect to the filter unit 51. In the filter unit 61 of Figure 4, the vertical pipe 62 is slidably mounted but the tube 63 is fixed relative to the filter unit 61. In the filter unit of Figure 5, the tube 73 is fixed, and the vertical pipe 72 is slidably mounted within a fixed sleeve 74. Thus, the level of the filtrate 32 remains fixed relative to the filter unit 71 as it is raised or lowered.

[0031] The variants shown in Figures 3 to 5 can be combined with either of the embodiments shown in Figures 1 and 2.

[0032] In the reactor 81 shown in Figure 6, the outlet 84 from the filter unit 83 has an upward loop 85 to ensure that the filter unit 83 is filled with liquid. In the reactor 91 shown in Figure 7, there is a tube 97 connecting the gas space in the reactor to the filtrate. The outlet 94 extends to the bottom of the filter unit 93 and there is an optional connection 96 between the outlet 94 and the space in the reactor. This connection 96 would tend to prevent any siphon effect and allow any gas

remaining in the filtrate to escape. Again, the filter unit 93 will be filled with filtrate.

[0033] In all the illustrate embodiments, the geometries of the reactor, the communication means (eg. the tube 27) and the filtrate section may be varied in size and in order to optimise the pressure fluctuations by exploiting resonance-like effects.

[0034] The invention will now be further illustrated in the following Examples which were conducted on a laboratory scale.

EXAMPLE I

[0035] A stainless steel tube, with a diameter of 4.8cm and a height of approximately 2 meters was filled with a hydrocarbon liquid and a fine powdered catalyst. The tube was operated as a slurry bubble column by bubbling gas through the slurry.

[0036] A filter unit was placed in the upper part of the reactor. The filter unit was made of Sika stainless steel sintered metal cylinder Type R20 produced by the company Pressmetall Krebsöge GmbH. The filter unit had an outer diameter of 2.5cm, a height of 25cm, and an average pore size of 20 μm .

[0037] In this particular experiment, the reactor was filled with a slurry consisting of a poly α -olefin liquid and approximately 10 weight % of a fine powdered cobalt on alumina catalyst. The particle size ranged from 30 to 150 μm . The catalyst was kept suspended by gas bubbling through the liquid. The gas was a mixture of H_2 , CO and N_2 of varying composition, and was fed with a superficial gas velocity of 4cm/s. The temperature in the reactor was 230°C, and the pressure was 30 bar ($3 \times 10^6 \text{ Pa}$).

[0038] The filtrate level inside the slurry was set approximately half way up in the valve.

[0039] The liquid formed by the Fischer-Tropsch reaction in the reactor was withdrawn through the filter unit. In addition, a poly α -olefin liquid fed to the reactor was also withdrawn through the filter unit. The liquid withdrawal varied from 320 to 2.5 g/h depending on the formation rate of the liquid product, and the feeding rate of the hydrocarbon liquid. The experiment lasted approximately 400 hours, and a total amount of liquid of 30 litres was withdrawn through the filter unit. The liquid level in the reactor was constant during the experiment, and no colour indicating presence of solid particles could be observed in the liquid.

EXAMPLE II

[0040] A glass tube, with a diameter of 22cm and a height of 2.5 meters was filled with hydrocarbon liquid (Monsanto heat transfer fluid, MCS 2313) and a fine alumina powder (average particle diameter approximately 75 μm). The content of alumina was approximately 15% by weight. The tube was operated as a slurry bubble column (SBC) by bubbling gas through the

slurry.

[0041] A filter member without a connection tube between the gas volume above the slurry phase and the gas volume above the product phase was placed in the upper part of the SBC. The filter member was made of a Sika fil 10 stainless steel sintered metal cylinder produced by Sintermetallwerk Krebsöge GmbH. The sinter cylinder had an outer diameter of 2.5cm, a height of 20cm, and an average pore size of 10µm.

[0042] In this particular experiment the slurry level was set to be at the top of the sinter cylinder. The pressure amplitude in the SBC was measured to be 6mBar, the pressure drop across the sinter metal wall was approximately 3-4 mBar (300-400Pa). The temperature in the slurry was 20°C, the pressure was 1 Bar (10⁵Pa) and the gas velocity was approximately 8cm/s.

[0043] At the start of the experiment, the flow of the filtrate through the sinter metal cylinder was about 1000ml per minute. After 4 hours the flow was reduced to zero due to clogging of the sinter metal wall on the slurry side.

[0044] When a similar experiment was carried out in an apparatus in which communication between the gas volumes was provided by a piece of pipe acting as a connection tube, the initial flow rate was maintained essentially at the same level throughout the experiment.

Claims

1. A method of conducting a continuous multi-phase catalytic reaction in which the product includes at least one liquid component and the catalyst is a finely divided solid, the method comprising: introducing reactants into a slurry (16) of reactants, product and catalyst in a reactor vessel (11); separating the liquid product (32) from the remainder of the slurry (16) by means of the filter member (13); and maintaining the slurry (16) in state of constant agitation by introducing gaseous components into the slurry (16) as a stream of bubbles; characterised by establishing a mean pressure differential of from 1 to 1000 mBar across the filter member (13) and causing fluctuations or oscillations about the mean pressure differential; and in which a gas space (29) above the slurry (16) is in communication with the filtrate (32) or any gas space (28) above the filtrate (32), in addition to any communication by way of the slurry itself.
2. A method as claimed in Claim 1, characterised in that the gaseous components include any gaseous reactants.
3. A method as claimed in Claim 1 or Claim 2, characterised in that the slurry (16) is maintained in a turbulent state by the gas bubbles.
4. A method as claimed in any preceding Claim, char-

acterised in that the slurry (16) is maintained at a level above the level of the product (32) on the filtrate side of the filter member (13), by means of a constant level device on the filtrate side of the filter member (13).

5. A method as claimed in any preceding Claim, characterised in that the fluctuations or oscillations are caused by the turbulent motion of the slurry (16).
6. A method as claimed in any preceding Claim, characterised in that the fluctuations or oscillations are achieved by applying a pulsating pressure to the gas volume (28) above the filtrate (32).
7. A method as claimed in any preceding Claim, characterised in that the mean differential pressure is less than 500 Pa.
8. A method as claimed in any preceding Claim, characterised in that fluctuations or oscillations are in the range of from 10% to 200% of the mean pressure differential.
9. A method as claimed in any preceding Claim, characterised in that the reactants are CO and H₂, the catalyst is a Fischer-Tropsch catalyst and the products are methanol and higher hydrocarbons.

Patentansprüche

1. Verfahren zur Durchführung einer kontinuierlichen katalytischen Mehrphasenreaktion, bei welcher das Produkt zumindest eine flüssige Komponente beinhaltet und der Katalysator ein fein verteilter Feststoff ist, wobei das Verfahren umfaßt:

Einführen der Reaktanden in eine Aufschlammung (16) von Reaktanden, Produkt und Katalysator in einen Reaktorbehälter (11); Trennung des flüssigen Produkts (32) vom Rest der Aufschlammung (16) mittels eines Filterelements (13); und Halten der Aufschlammung (16) in einem Zustand konstanter Bewegung durch Einführung gasförmiger Komponenten in die Aufschlammung (16) in Form eines Stroms von Blasen; charakterisiert durch Erzeugung eines Hauptdruckdifferentials von 1 bis 1000 mbar über das Filterelement (13) und Erzeugung von Fluktuationen oder Oszillationen um das Hauptdruckdifferential;

und bei welchem ein Gasraum (29) über der Aufschlammung (16) mit dem Filtrat (32) oder irgendeinem Gasraum (28) oberhalb des Filtrats (32) in Verbindung steht und zwar zusätzlich zu irgendeiner Verbindung über die Aufschlammung selbst.

2. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** die gasförmigen Komponenten irgendwelche gasförmigen Reaktanden beinhalten.

3. Verfahren nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** die Aufschlammung (16) in einem turbulenten Zustand durch die Gasblasen gehalten wird.

4. Verfahren nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Aufschlammung (16) auf einem Niveau oberhalb des Niveaus des Produkts (32) auf der Filtratseite des Filterelements (13) mittels einer Einrichtung zur Aufrechterhaltung eines konstanten Niveaus auf der Filtratseite des Filterelements (13) gehalten wird.

5. Verfahren nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Fluktuationen oder Oszillationen durch die turbulente Bewegung der Aufschlammung (16) verursacht werden.

6. Verfahren nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Fluktuationen oder Oszillationen durch Aufbringung eines pulsierenden Drucks auf das Gasvolumen (28) oberhalb des Filtrats (32) erreicht werden.

7. Verfahren nach einem der vorhergehenden Ansprüche **dadurch gekennzeichnet, dass** der Hauptdruckdifferenzdruck weniger als 500 Pa ist.

8. Verfahren nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** Fluktuationen oder Oszillationen im Bereich von 10 % bis 200 % des Hauptdruckdifferentials sind.

9. Verfahren nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** die Reaktanden CO und H₂, der Katalysator ein Fischer-Tropsch-Katalysator und die Produkte Methanol und höhere Kohlenwasserstoffe sind.

Revendications

1. Procédé pour conduire une réaction catalytique multi-phase en continu, dans lequel le produit inclut au moins un composant liquide et le catalyseur est un solide finement divisé, le procédé consistant: à introduire des réactifs dans une suspension (16) de réactifs, le produit et le catalyseur dans un récipient réactionnel (11); à séparer le produit liquide (32) du reste de la suspension (16) à l'aide d'un élément de filtre (13); et à maintenir la suspension (16) à l'état d'agitation constante en introduisant des composants gazeux dans la suspension (16) sous forme

d'un courant de bulles; caractérisé par l'établissement d'une pression différentielle moyenne de 1 à 1 000 mbar à travers l'élément de filtre (13) et à provoquer des fluctuations ou des oscillations autour de la pression différentielle moyenne; et dans lequel un espace gazeux (29) au-dessus de la suspension (16) est en communication avec le filtrat (32) ou tout espace gazeux (28) au-dessus du filtrat (32), en plus de toute communication par l'intermédiaire de la suspension elle-même.

2. Procédé selon la revendication 1, caractérisé en ce que les composants gazeux incluent tout réactif gazeux.

3. Procédé selon la revendication 1 ou 2, caractérisé en ce que la suspension (16) est maintenue à l'état turbulent par les bulles de gaz.

4. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que la suspension (16) est maintenue à un niveau au-dessus du niveau du produit (32) sur le côté du filtrat de l'élément de filtre (13), à l'aide d'un dispositif à niveau constant sur le côté du filtrat de l'élément de filtre (13).

5. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que les fluctuations ou oscillations sont provoquées par le déplacement turbulent de la suspension (16).

6. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que les fluctuations ou oscillations sont réalisées en appliquant une pression pulsatoire au volume gazeux (28) au-dessus du filtrat (32).

7. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que la pression différentielle moyenne est inférieure à 500 Pa.

8. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que les fluctuations ou les oscillations sont comprises entre 10% et 200% de la pression différentielle moyenne.

9. Procédé selon l'une quelconque des revendications précédentes, caractérisé en ce que les réactifs sont CO et H₂, le catalyseur est un catalyseur Fischer-Tropsch et les produits sont le méthanol et les hydrocarbures supérieurs.

